Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle de l'énergie atomique
C.P. 1046
Ottawa, Canada
K1P 5S9

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# MEMBRANE BARRIERS FOR RADON GAS FLOW RESTRICTIONS

by

J.F. Archibald, Ph.D., P. Eng.
Queen's University

A research report prepared for the
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**RESEARCH REPORT**

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# MEMBRANE BARRIERS FOR RADON GAS FLOW RESTRICTIONS

A study prepared by James F. Archibald of the Queen's University Mining Engineering Department under contract to the Atomic Energy Control Board.

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ABSTRACT

Research was performed to assess the feasibility of barrier membrane substances, for use within mining or associated high risk environments, in restricting the diffusion transport of radon gas quantities. Specific tests were conducted to determine permeability parameters of a variety of membrane materials with reference to radon flow capabilities.

Tests were conducted both within laboratory and in-situ emanation environments where concentrations and diffusion flows of radon gas were known to exist. Equilibrium radon gas concentrations were monitored in initially radon-free chambers adjacent to gas sources, but separated by specified membrane substances. Membrane barrier effectiveness was demonstrated to result in reduced emanation concentrations of radon gas within the sampling chamber atmosphere. Minimum gas concentrations were evidenced where the barrier membrane material was shown to exhibit lowest radon permeability characteristics.

RÉSUMÉ

On a mené une étude de faisabilité relative aux matériaux à utiliser comme barrières de diffusion du radon à l'état gazeux, autant dans l'industrie minière que dans d'autres milieux associés où le risque est élevé. Divers matériaux pouvant servir de barrières au radon ont été mis à l'essai afin de déterminer leurs paramètres de perméabilité.

On a effectué des essais en laboratoire et sur place dans des milieux où l'on savait qu'il y avait des concentrations et des diffusions de radon. Les concentrations de radon en équilibre ont été contrôlées dans des chambres vides de radon au départ et adjacentes aux sources de gaz, mais séparées par des matériaux précis utilisés comme barrières. On a pu démontrer que les barrières s'étaient avérées efficaces en réduisant les concentrations de radon dans l'atmosphère de la chambre d'échantillonnage. Les plus petites concentrations de gaz ont été décelées où la perméabilité au radon du matériau était la plus faible.

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## 1.0 INTRODUCTION

This research contract, awarded at the beginning of March, 1984, was implemented during the interval between March - August, 1984.

Following discussions between Dr. Harold Stocker, Mr. A.B. Dory and Mr. E. Rabin of the Atomic Energy Control Board, Mr. J. Poupore of Diamond P Products Limited, Ottawa, Ontario, and Dr. J.F. Archibald of the Mining Engineering Department of Queen's University, Kingston, Ontario, a research investigation entitled "Membrane Barriers for Radon Gas Flow Restrictions" was authorized by the Atomic Energy Control Board.

The proposed work program was initiated for the purpose of investigating the permeability characteristics of membrane layers with reference to radon gas flow. The prime objective of the program was to assess the sealant capabilities of certain membrane materials for use in environmental conditions subject to radon hazard potential.

## 2.0 METHODOLOGY

### 2.1 Laboratory Phase

A series of permeability determinations were conducted within the Mine Environment Laboratory of the Mining Engineering Department, Queen's University. Techniques have been previously reported in the literature which develop the basic sampling procedures for permeability assessment[1,2,3,4]. Similar techniques were adopted for the purposes of this study and will be briefly explained.

The general technique, as developed by Jha, Raghavayya and Padmanabhan[1], involves measurement of radon concentration ratios across membrane substances of interest under steady state conditions. The general configuration of the laboratory test apparatus is illustrated in the schematic diagram of Figure 1.

A high strength radon gas source was established within a sealed steel vessel having an approximate wall thickness of 0.635 cm. A continuous flow of radon gas was pumped into this vessel from a Pylon Electric Development Company Type 150-AB Rn-222 Gas Source. The in-line source of radon gas is produced from a radium salt concentration of approximately $1.83 \times 10^6$ pCi strength. Radon quantities were circulated through the source vessel continuously, during each test, by pumping gas from the Pylon source at the rate of one litre per minute. For such flows, radon gas is generated at the rate of 100 pCi/minute at a calibrated ac-

curacy of ±4%. Regulated inflows were maintained using a Manostat Model J peristaltic pump.

A second steel vessel, identical to the source chamber and exhibiting physical dimensions as illustrated in the sketch of Figure 1, was utilized as a detector vessel. Between the source and detector vessels, a perforated aluminum disc was inserted to act as a filter stage upon which the various membrane barriers would be mounted. Membranes, inserted upon the filter stage between the source and detector chambers, were sealed to prevent gas or air leakage using 0 - ring mounts, as illustrated. The 0 - ring seals were utilized to restrict radon flow outward to the atmosphere from either the source or detector vessel stages, and to prevent direct radon gas flow between the two vessel stages by means other than diffusion.

Air from within the detection vessel was circulated continuously through an alpha scintillation assembly and back into the detector vessel using a Gilian Instrument Corporation Model HFS11BA Portable Sampling Pump, at a fixed flow rate of one litre per minute. Alpha activity within this circulating air stream was continuously monitored using standard silver-activated zinc sulphide coated scintillation cells mounted within an EDA Electronics Limited RDA-200 Radon Gas Detector (photo-multiplier/counter assembly). Scintillation cell activity response was calibrated using the Pylon Model 150-AB Radon Gas Source to a similar degree of accuracy of ±4%.

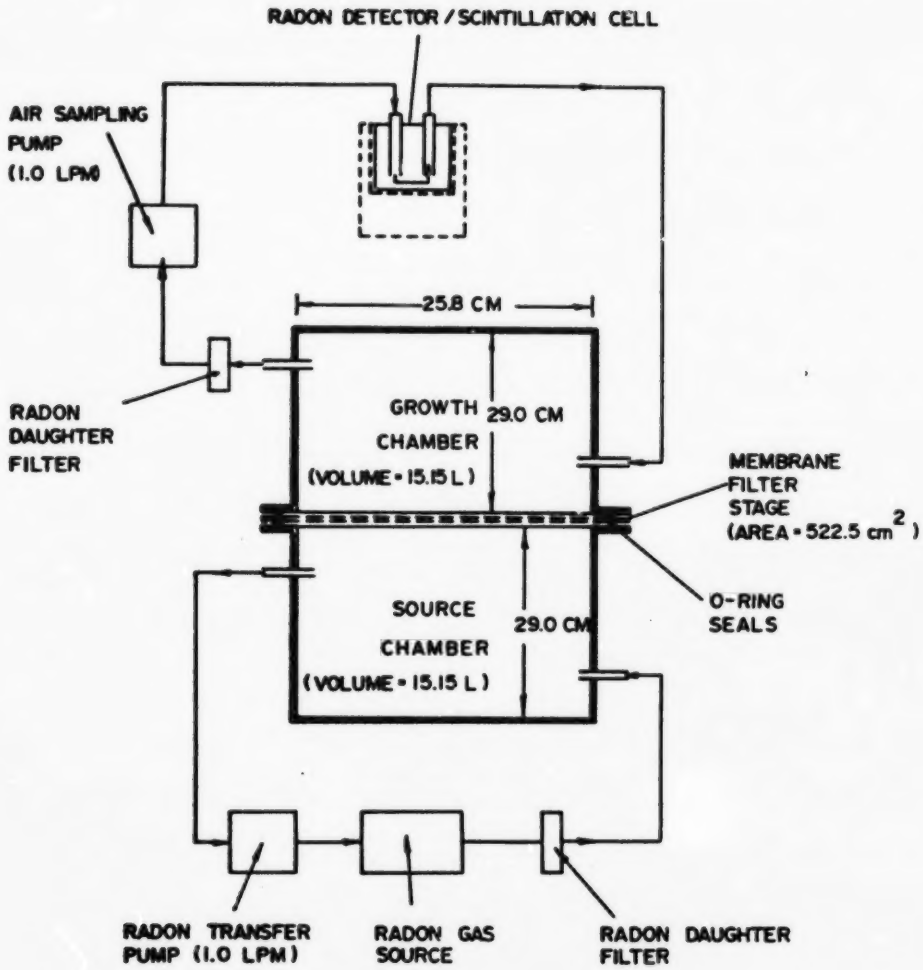


FIGURE 1 - SCHEMATIC VIEW OF RADON GAS TEST APPARATUS

Air flows, prior to entering the source vessel from the radon source and the scintillation cell from the detector vessel, were filtered to remove radon daughters. No differential pressure effects were observed to occur between the source and sampling chambers during any of the membrane tests.

Prior to each test, the source vessel, detector vessel and filter stage were placed within a fresh air stream to remove the presence of any contaminant gas sources. The source and detector vessels were subsequently coupled, with the filter stage and appropriate filter media being placed between the stages. Upon complete installation, circulating air flows within the source and detector vessels were initiated at similar uniform rates of one litre per minute. Alpha activity within the detector vessel volume was thereafter monitored on a routine basis for periods up to seventeen days (approximately $2.5 \times 10^4$ minutes) until equilibrium alpha activity response was observed to occur. Under such conditions, equilibrium radon gas concentrations were estimated to exist within the detection vessel as the result of diffusion transport of radon through the filter membrane barriers alone.

### 2.1.1 Description of Membrane Materials

A series of commercially - available membrane materials were selected for testing on the basis of availability and on the basis of potential for use in underground mining or construction

environments where radon barriers may be needed. A total of six membrane materials were chosen, and are listed below:

i) Open cell polyurethane (PU) in 0.635 cm sheet thickness

ii) Aluminized mylar sheeting (polyethylene teresphthalate (PT)), in 0.0089 cm sheet thickness.

iii) Rock Coat 82-3, a polyvinyl chloride copolymer (PVC), in 0.127 cm sheet thickness

iv) LP$^{(R)}$ polysulphide copolymer (PS), in 0.012 cm sheet thickness

v) Latex rubber (LR), in 0.0203 cm sheet thickness, and

vi) Polyethylene (PE), in .010 cm sheet thickness.

Samples of polyurethane (PU), aluminized mylar (PT), latex rubber (LR) and polyethylene (PE) were obtained from standard commercial sources in prepared sheet form having designated thicknesses as given. Product information concerning the standard chemical and physical nature of these materials is available in occupational health and safety and/or chemical reference

literature, and will not be referenced in this report.

Samples of Rock Coat 82-3 (PVC) and LP(R) polysulphide copolymer (PS) membrane substances were specifically manufactured for use in this test program, and will therefore be referenced individually.

Rock Coat 82-3, supplied by J. Poupore of Diamond P Products Limited of Ottawa, and manufactured by Halltech Incorporated of West Hill, Ontario, is a 30% by weight solution of PVC copolymer in an acetone solvent. Product specifications and pertinent physical characteristics are reported in a Material Safety Data Sheet appended to this report. This material was formulated for use within the Canadian mining industry as a spray-type wall coating to provide both lighting efficacy and underground wall support benefits. Under certain conditions, the use of such a coating agent would be beneficial in uranium mine environments should it prove to act as a radon gas flow retardant. For such reasons, Rock Coat 82-3 was selected for investigation.

LP(R) polysulphide copolymer, similarly identified by the trade name "WD-6" by its manufacturer, the Thiokol Corporation of Montreal, Quebec is an alkyl polysulphide copolymer in a water solvent. Product specification data, similar to that given for the Rock Coat 82-3 material, is presented in the report appendix.

On the basis of product data, similarly appended, which evidences that polysulphide compounds exhibit significant resistance to gamma irradiation with little physical degradation, the utility of such compounds for radon flow restriction was anticipated. Product samples, obtained by Mr. Poupore, were therefore also included in this research program.

## 2.2 In-Situ Investigation

A series of in-situ emanation rate studies were performed underground at a mining facility in the Elliot Lake region during the study period between May - August, 1984. Such tests were effected to both verify the results of controlled laboratory experiments in-situ as well as to determine the efficacy of installing the various membrane materials on emanating excavation surfaces.

An initial visit to the mine underground workings was made by the author and a student assistant between May 21 - May 23, 1984, for the purpose of preparing and coating a suitable excavation surface with several membrane substances. Analysis of in-situ emanation rate behaviour of rock and bulkhead surfaces is a standard characterization technique which has been utilized often in the Canadian uranium mining industry [5,6,7]. For the purposes of this research project, surface area emanation rate parameters (Js) and the growth of radon gas concentrations within

sealed chambers placed on a wooden bulkhead surface were measured.

In-situ tests were permitted by the host mining organization on condition that a bulkhead, rather than an ore, surface would be observed. Present interests within the mine organization are such that priority examination of bulkhead sealant capabilities are of major concern. Based upon previous experience by the author at this mine, it is expected that reduced emanation rate behaviour through bulkhead surfaces, when compared with ore emanating surfaces, would be observed. Only in cases where extreme differences in radon concentrations between adjacent bulkhead sides exist would rate conditions, similar to those that may be measured at ore/excavation interfaces, be similar. A bulkhead site was selected which provided separation between a sealed stope, exhibiting no air flow conditions, and an exhaust airway, exhibiting significant air flow. All tests and barrier material placements were performed upon the exhaust airway side of the bulkhead which will exhibit low level radon concentrations with respect to the sealed stope side.

The surface chamber technique which is utilized to perform emanation rate tests involves the following general procedures:

a) a sampling chamber, consisting of a cylindrical, air-tight, stainless steel vessel approximately

30.5 cm in width by 38.1 cm long, is placed upon the prepared bulkhead surface.

b) the chamber/bulkhead contact surfaces are sealed with a silicone caulk to preclude any escape of radon gas from within the chamber.

c) each chamber, as placed, is provided with two air valves through which pressurized air can be passed or from which internal air samples may be removed; upon initial installation, radon-free compressed air is blown through the chamber to void any enclosed radon gas concentrations which may exist within the ambient mine air.

d) since the principle of rate calculation is based upon measurement of increasing radon concentrations within the chamber over short time intervals, the initial time of chamber placement or voidance is recorded; subsequently, radon which may diffuse through the bulkhead will collect within the chamber.

e) samples of radon-laden air from the chamber are then drawn through the chamber air valves into previously calibrated, evacuated scintillation flasks. Each sample is drawn through a millipore

filter to pre-screen airborne radon daughter particles, thereby insuring that only radon gas is collected into the flask.

f) the activity of the contained radon gas was measured to determine radon gas concentrations. From these results, the radon flux or emanation rate (Js) parameters for diffusion flow from the treated bulkhead surfaces are calculated according to the following relationship:

$$Js = K \times C \times \frac{V}{A}$$

where: Js = emanation rate; ($Ci/cm^2/s$)

K = depletion factor, equal to $\frac{\lambda}{1-e^{-t}}$

$\lambda$ = decay constant for radon, equal to $2.1 \times 10^{-6}$ disintegrations/s

C = radon concentration of air within chamber measured at time (t); (pCi/L)

V = volume of air within chamber; (L)

A = exposed emanating surface area; ($cm^2$)

t = time interval between chamber placement/ voidance and air sample collection; (hours)

Due to the limited nature of tests and resources available, the present in-situ study was limited to placement of collection chambers only on bulkhead surfaces and to the examination of two barrier membrane materials. A total of three collection chambers were installed, at closely adjacent bulkhead sites, for the following test conditions:

i) one chamber was placed directly upon the bulkhead surface, which comprises one untreated, 0.95 cm thick plywood sheet nailed directly to a wooden frame. Each side of the bulkhead frame was sheathed by a similar thickness of plywood, and no provision was made to seal gaps between adjacent plywood sections. This case was utilized to model the existing barrier effect of regular plywood bulkhead materials.

ii) a second chamber was placed upon the bulkhead surface to which a layer coating of aluminized

mylar (PT), of caliper measured thickness equal to 0.023 ± .002 cm, was first affixed. Both the chamber/aluminized mylar and aluminized mylar/bulkhead contact surfaces were sealed using silicone caulk prior to initiating emanation rate tests.

iii) a third and final chamber was placed upon the bulkhead surface to which a layer coating of polysulphide copolymer (PC), approximately 0.064 cm thick, had been affixed by brushing. Layer thickness was measured using calipers to an accuracy of ± .002 cm.

During each series of site measurements, one sample of air was recovered from each chamber. For each case, radon gas concentration measurements were performed and emanation rate determinations were performed between each set of air sampling tests. Similarly, one sample of mine air from each side of the bulkhead was taken at each sampling interval to assess ambient concentration conditions existing adjacent to the sampling site.

## 3.0 DESCRIPTION OF EXPERIMENTAL RESULTS

### 3.1 Laboratory Phase Tests

On the basis of previously published research[1], it has been shown that the use of polyurethane foam (PU) barrier membranes offers unrestricted flow of radon gas from source to detection vessel chambers, while retarding the transport of radon daughter products. For each membrane test, scintillation cell readings of circulated detection vessel air were recorded until steady state count rates were achieved. Upon achievement of steady state radon concentration conditions within the detection stage, air samples were collected from the source vessel, and absolute radon concentrations were determined. In such a manner, uniform source chamber concentrations of radon were able to be observed and checked.

During the initial test, using polyurethane foam as the sole membrane medium, the observed steady state count rate (Co) was measured to be $1.6226 \times 10^4$ cpm. The radon concentration within the source chamber, as determined by scintillation cell tests, averaged $6.64 \times 10^4$ pCi/L. For all membrane barrier tests, a value of Co equal to $1.6226 \times 10^4$ cpm was therefore assumed to be the maximum possible detection chamber activity rate.

The experiment was subsequently repeated without removal of the polyurethane bed on the aluminum support stage. Other

membrane materials were placed directly upon the polyurethane material, and tests were repeated until steady state activity was recorded.

Curves illustrating the detection chamber radon activity versus growth time are presented in Figures 2 and 3 to illustrate both linear and logarithmic data effects. Data which was utilized to manufacture these curves is presented in Table 1.

The concentration of radon gas in the detection vessel is identical to that within the source vessel for the case in which polyurethane foam, alone, is used as the membrane medium. Where both concentrations are equivalent it is indicated that polyurethane exhibits complete permeability to radon diffusion.

Where a detection vessel concentration, less than that which exists in the source vessel, occurs, a measure of filter impermeability to radon diffusion is inferred. The concentration of radon in the detection chamber will be proportional to the alpha count rate (Cd) which is measured. The ratio of detection vessel to source vessel count rates, Cd/Co, is expressed as a measure of filter permeability to radon, and is designated as a ratio parameter, $R^1$. This parameter may be used to derive the membrane permeability constant, k, values based upon the expression:

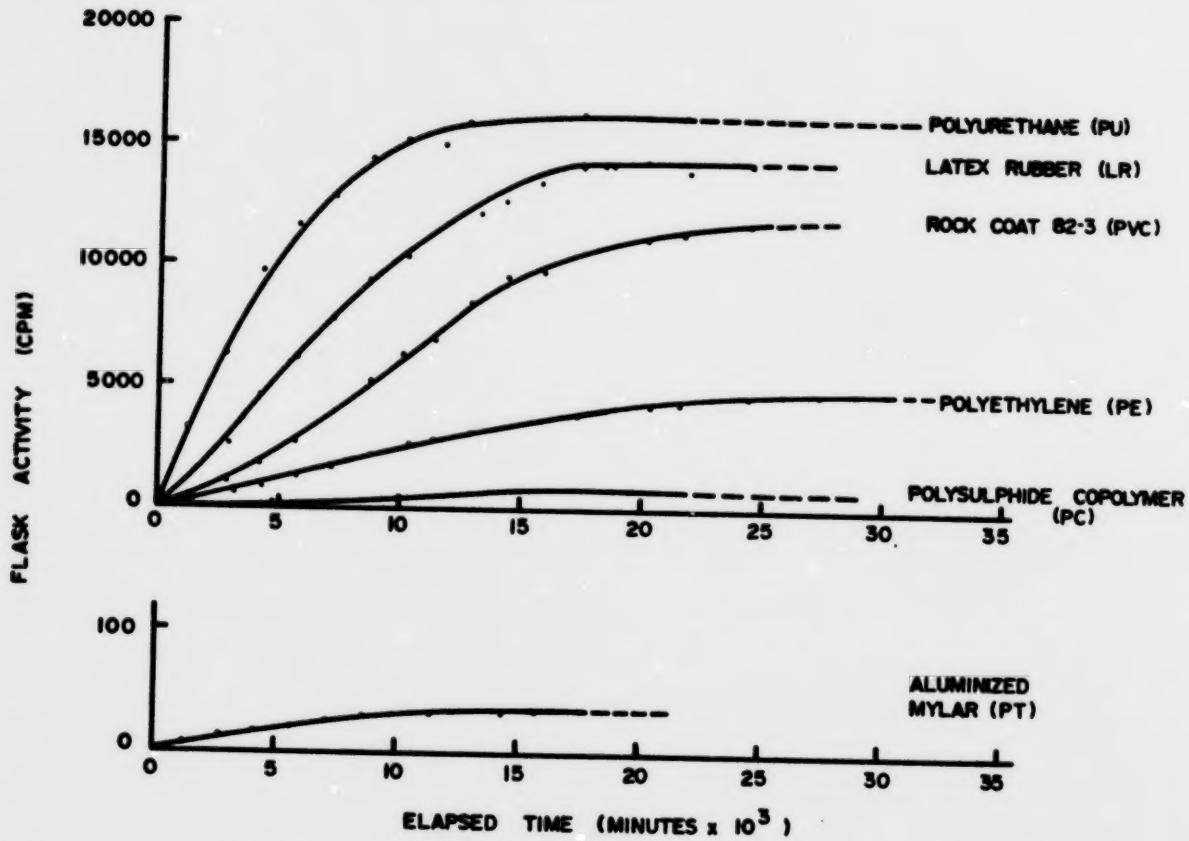


FIGURE 2 - DETECTOR VESSEL ACTIVITY VERSUS TIME (LINEAR PLOT)

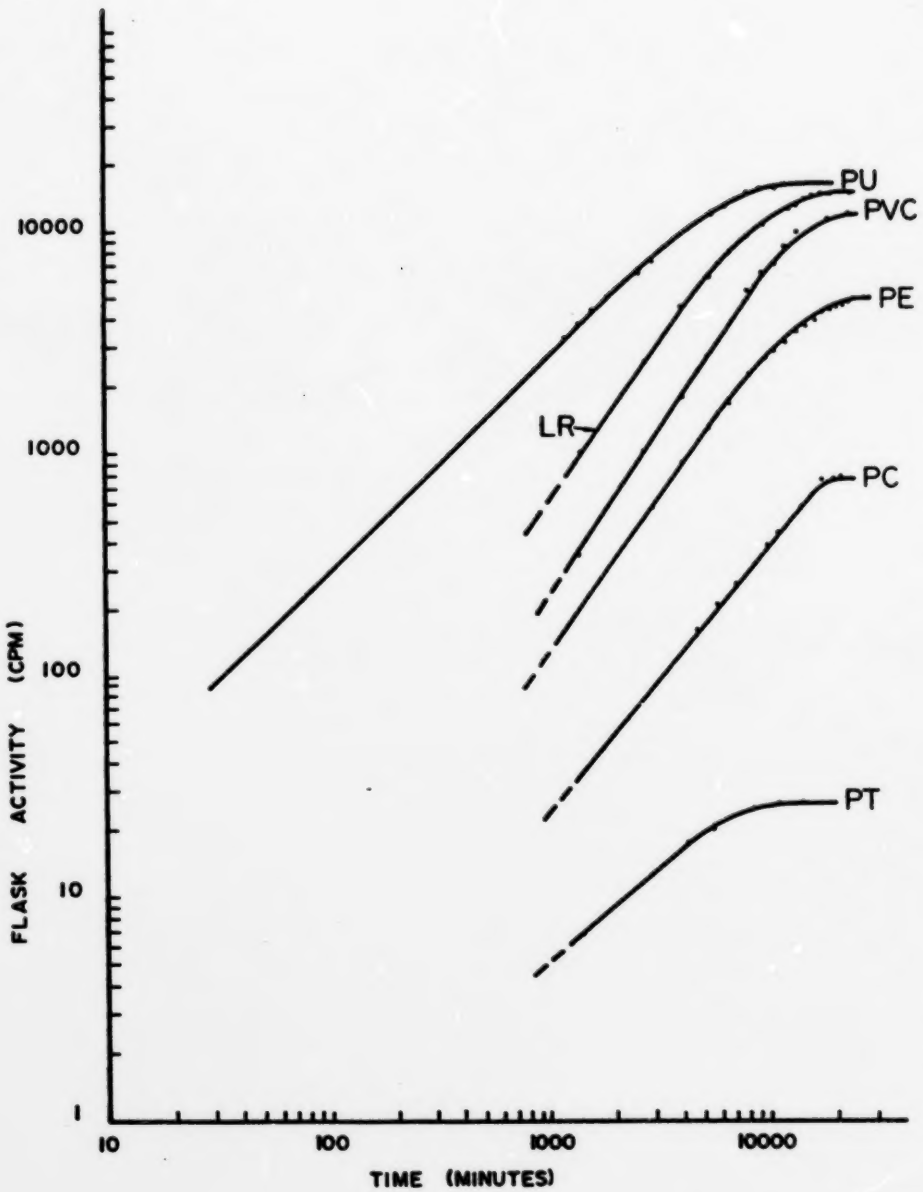


FIGURE 3- DETECTOR VESSEL ACTIVITY VERSUS TIME (LOG PLOT)

A) POLYURETHANE FOAM (PV)

| Time | ΔT (minutes) | Count Rate (cpm) | Remarks |
|---|---|---|---|
| April 6, 11:10 AM | 0 | 0 | - 0.635 cm thickness, open cell type |
| April 7, 8:15 AM | 1265 | 3293 | |
| April 8, 8:25 AM | 2715 | 6271 | |
| April 9, 11:20 AM | 4330 | 9743 | |
| April 10, 9:00 AM | 5630 | 11552 | |
| April 11, 11:10 AM | 7200 | 12781 | - Concentration in source chamber |
| April 12, 11:15 AM | 8645 | 14426 | @ ΔT = 21820 minutes |
| April 13, 11:05 AM | 10075 | 15091 | @ 66400 pCi/L |
| April 14, 3:20 PM | 11770 | 14976 | |
| April 15, 8:20 AM | 12790 | 15896 | |
| April 18, 8:20 AM | 17500 | 16200 | |
| April 21, 8:20 AM | 21820 | 16226 | - Co = Cd = 16226 cpm. |

B) ALUMINIZED MYLAR (PT)

| Time | ΔT (minutes) | Count Rate (cpm) | Remarks |
|---|---|---|---|
| April 22, 8:20 AM | 0 | 0 | - .0089 cm thickness, single sheet |
| April 23, 8:20 AM | 1440 | 7 | |
| April 24, 8:10 AM | 2870 | 12 | |
| April 25, 8:25 AM | 4325 | 18 | - Concentration in source chamber |
| April 26, 8:15 AM | 5750 | 20 | @ ΔT = 15840 minutes |
| April 27, 8:35 AM | 7215 | 23 | 66482 pCi/L |
| April 28, 8:20 AM | 8640 | 25 | |
| April 30, 8:25 AM | 11525 | 26 | |
| May 2, 8:20 AM | 14400 | 25.5 | |
| May 3, 8:20 AM | 15840 | 26.5 | - Cd = 26.5 cpm |

TABLE 1 - DETECTION CHAMBER COUNT RATE ACTIVITY VERSUS TIME DATA FOR MEMBRANE BARRIER TESTS

C) ROCK COAT 82-3 (PVC)

| Time | ΔT (minutes) | Count Rate (cpm) | Remarks |
|---|---|---|---|
| May 4, 9:30 AM | 0 | 0 | - 0.127 cm thickness |
| May 5, 8:50 AM | 1400 | 355 | |
| May 6, 8:20 AM | 2810 | 1006 | |
| May 7, 8:15 AM | 4245 | 1786 | |
| May 9, 8:15 AM | 5685 | 2705 | |
| May 10, 9:30 AM | 8640 | 5239 | |
| May 11, 8:15 AM | 10005 | 6359 | - Concentration in source chamber |
| May 12, 8:15 AM | 11445 | 6904 | @ ΔT = 24500 minutes |
| May 13, 8:10 PM | 12880 | 8486 | @ 66515 pCi/L |
| May 14, 8:55 PM | 14365 | 9510 | |
| May 15, 9:00 AM | 15810 | 9689 | |
| May 18, 8:25 AM | 20100 | 11206 | |
| May 19, 8:30 AM | 21545 | 11464 | |
| May 20, 8:20 AM | 22975 | 11706 | - Cd = 11950 cpm |
| May 21, 8:20 AM | 24415 | 11840 | |

D) POLYSULPHIDE COPOLYMER (PC)

| Time | ΔT (minutes) | Count Rate (cpm) | Remarks |
|---|---|---|---|
| May 22, 9:00 AM | 0 | 0 | - 0.012 cm thickness |
| May 23, 2:05 PM | 1745 | 46 | |
| May 25, 5:30 PM | 4830 | 164 | |
| May 26, 1:30 PM | 6030 | 203 | |
| May 27, 1:25 PM | 7465 | 250 | |
| May 29, 1:30 PM | 10355 | 390 | - Concentration in source chamber |
| May 30, 1:30 PM | 11790 | 438 | @ ΔT = 21900 minutes |
| June 1, 2:10 PM | 14710 | 587 | @ 66387 pCi/L |
| June 2, 1:35 PM | 16115 | 747 | |
| June 3, 1:35 PM | 17555 | 695 | |
| June 4, 1:30 PM | 18990 | 756 | |
| June 5, 1:35 PM | 20435 | 741 | |
| June 6, 1:35 PM | 21875 | 751 | - Cd = 756 cpm |

TABLE 1 (cont'd)- DETECTION CHAMBER COUNT RATE ACTIVITY VERSUS TIME DATA FOR MEMBRANE BARRIER TESTS

E) LATEX RUBBER (LR)

| Time | | ΔT (minutes) | Count Rate (cpm) | Remarks |
|---|---|---|---|---|
| June 7 | 10:00 AM | 0 | 0 | - 0.0203 cm thickness |
| June 9, | 9:35 AM | 2855 | 2584 | |
| June 10, | 8:05 AM | 4205 | 4541 | - Concentration in source chamber @ ΔT = 24420 minutes @ 66524 pCi/L |
| June 11, | 8:00 AM | 5640 | 6116 | |
| June 12, | 8:00 AM | 7080 | 7758 | |
| June 13, | 8:05 AM | 8625 | 9295 | |
| June 14, | 8:05 AM | 10065 | 10391 | - Cd = 14375 cpm |
| June 15, | 4:10 PM | 13330 | 12055 | |
| June 16, | 8:10 AM | 14290 | 12613 | |
| June 17, | 7:55 AM | 15715 | 13418 | |
| June 18, | 1:15 PM | 17475 | 14171 | |
| June 19, | 8:10 AM | 18670 | 14252 | |
| June 20, | 8:00 AM | 20100 | 14375 | |
| June 21, | 12:35 PM | 21815 | 13950 | |
| June 22, | 8:10 AM | 24420 | 14241 | |

E) POLYETHYLENE (PE)

| Time | ΔT (minutes) | Count Rate (cpm) | Remarks |
|---|---|---|---|
| June 18, 10:45 AM | 0 | 0 | - 0.01016 cm thickness, single sheet |
| June 19, 9:15 AM | 1290 | 173 | |
| June 20, 1:45 PM | 3060 | 561 | |
| June 21, 9:30 AM | 4245 | 910 | |
| June 22, 8:20 AM | 5635 | 1280 | - Concentration in source chamber @ |
| June 23, 8:10 AM | 7065 | 1645 | ΔT = 30185 minutes |
| June 24, 12:25 PM | 8770 | 2209 | @ 66085 pCi/L |
| June 25, 3:35 PM | 10390 | 2631 | |
| June 26, 7:55 AM | 11465 | 2828 | |
| June 27, 8:15 AM | 12920 | 3129 | - Cd = 4887 cpm. |
| June 28, 8:10 AM | 14355 | 3470 | |
| June 29, 8:10 AM | 15795 | 3661 | |
| June 30, 10:15 AM | 17355 | 3880 | |
| July 1, 11:50 AM | 18890 | 4226 | |
| July 2, 1:25 AM | 20425 | 4367 | |
| July 3, 7:42 AM | 21522 | 4410 | |
| July 4, 7:40 AM | 22960 | 4593 | |
| July 5, 8:10 AM | 24430 | 4708 | |
| July 6, 7:50 AM | 25850 | 4861 | |
| July 7, 9:25 AM | 27385 | 4886 | |
| July 8, 9:45 AM | 28845 | 4887 | |
| July 8, 7:45 AM | 30165 | 4819 | |

$$R = \left[ 1 + \frac{\lambda T \; V_1 \; V_2}{kA(V_1 + V_2)} \right]^{-1}$$

where R = count ratio of $\frac{\text{detection chamber steady state activity rate}}{\text{peak case steady state activity rate}}$

$\lambda$ = radon decay constant; ($2.1 \times 10^{-6}$ disintegrations/s)

T = membrane barrier thickness; (cm)

$V_1$ = source chamber volume; ($cm^3$)

$V_2$ = detection chamber volume; ($cm^2$)

k = membrane material permeability constant; ($cm^2.sec^{-1}$)

A = membrane area through which radon diffusion flow occurs; ($cm^2$)

A summary of filter physical property parameters is listed in the data of Table 2.

## 3.2 In-Situ Tests

The results of radon concentration and emanation rate behaviour determinations performed upon the three bulkheads sites

| FILTER MATERIAL | THICKNESS (cm) | R (Cd/Co) | Permeability Constant, k ($cm.sec^{-1}$) |
|---|---|---|---|
| Polyurethane (PU) | $6\ 35 \times 10^{-1}$ | 1 | - |
| Aluminized Mylar (PT) | $8.90 \times 10^{-3}$ | $1.633 \times 10^{-3}$ | $4.426 \times 10^{-10}$ |
| Rock Coat 82-3 (PVC) | $1.27 \times 10^{-1}$ | $7.365 \times 10^{-1}$ | $1.079 \times 10^{-5}$ |
| Polysulphide Copolymer (PC) | $1.02 \times 10^{-1}$ | $4.659 \times 10^{-2}$ | $1.515 \times 10^{-7}$ |
| Latex Rubber (LR) | $2.03 \times 10^{-2}$ | $8.859 \times 10^{-1}$ | $4.794 \times 10^{-6}$ |
| Polyethylene (PE) | $1.02 \times 10^{-2}$ | $3.012 \times 10^{-1}$ | $1.331 \times 10^{-7}$ |

TABLE 2 - FILTER MEMBRANE PHYSICAL PROPERTY SUMMARY

are listed in Table 3 and illustrated in the curves of Figure 4. No estimates of permeability ratio (R) values or permeability constant (k) values are possible to be made for direct comparison with laboratory - derived data due to the additional effects of bulkhead constituent materials. The in-situ concentration and rate parameters do serve, however, to illustrate relative benefits achieved through use of each membrane substance material.

An approximate ratio parameter value, designated R', may be inferred by comparing the peak emanation chamber radon concentration versus the sealed airway radon concentration values. Such data is listed in Table 3. One sampling chamber was affixed upon a uniform, unbroken section of the untreated plywood surface. The other two chambers and membrane layers were affixed to adjacent plywood surfaces where plywood sections, fitted together, exhibited gaps between each section. Where treated surface tests were conducted, the presence of the gapped plywood surface layer would offer little resistance to radon diffusion flow; thus, only the membrane layer materials would be responsible for attenuating radon concentration levels within the sampling chambers at these sites.

| DATE | Δ T (Minutes) | RADON CONCENTRATION (pCi/L) | | | | | EMANATION RATE, Js ($pCi/m^2/s \times 10^{-18}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Chamber on Untreated Bulkhead | Chamber on Polysulphide Copolymer Surface | Chamber on Aluminized Mylar Surface | In Exhaust Airway | In Sealed Airway | Chamber on Untreated Bulkhead | Chamber on Polysulphide Copolymer Surface | Chamber on Aluminized Mylar Surface |
| 23/5/84 | 0 | - | - | - | 60.7 | 147.8 | - | - | - |
| 28/5/84 | 7155 | - | - | - | 47.5 | 128.7 | - | - | - |
| 30/5/84 | 10275 | - | - | - | 43.4 | 122.1 | - | - | - |
| 1/6/84 | 11720 | 3.7 | - | Too low to | - | - | 33.3 | - | - |
| 1/6/84 | 11810 | - | 2.9 | measure | - | - | - | 8.5 | - |
| 5/6/84 | 17710 | 21.2 | 14.5 | 0.8 | 31.2 | 129.4 | 2.0 | 1.1 | 0.075 |
| 6/6/84 | 18950 | 22.7 | 14.3 | 1.2 | - | - | 0.1 | - | 0.20 |
| 13/6/84 | 30270 | - | - | 2.5 | 34.6 | 98.2 | - | - | 0.068 |
| 22/6/84 | 43160 | $C_d'$ =23.7 | $C_d'$=17.5 | $C_d'$=2.6 | - | - | 0.024 | 0.059 | 0.046 |
| 29/6/84 | 53240 | - | - | | $C_e'$=38.0 | $C_e'$=100.7 | - | - | - |
| | | R' = 0.235 | 0.174 | 0.026 | | | | | |

TABLE 3 - IN-SITU GROWTH ACTIVITY OF RADON GAS AT BULKHEAD SAMPLING SITES

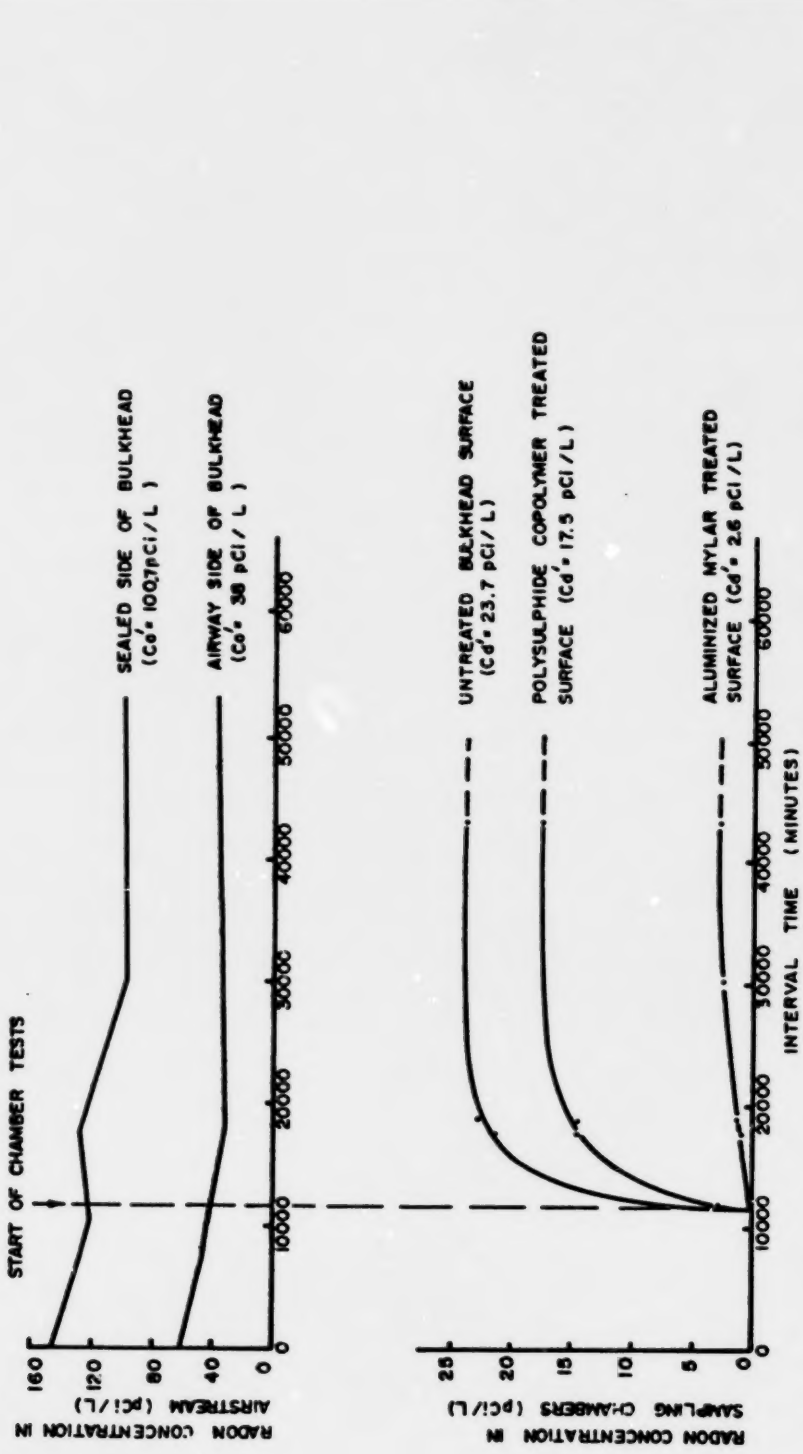


FIGURE 4 - GROWTH ACTIVITY IN SAMPLING CHAMBERS AND AMBIENT AIR CONCENTRATIONS VERSUS TIME AT BULKHEAD SAMPLING SITES

## 4.0 DISCUSSION OF RESULTS

On the basis of laboratory tests on various membrane materials, two substances were demonstrated to exhibit superior performance for reduction of radon emanation flows.

In general, the effectiveness of radon barrier materials will be demonstrated by the radon count rate ratio parameter, R. Variation in the R value, as evidenced in the results of Table 2, is dependent only upon the membrane thickness and permeability constant (k) parameters. Due to the nature of fabrication, no uniform membrane thickness was possible to be maintained for the purpose of this study. Samples of "Rock Coat 82-3" and the polysulphide copolymer materials were applied in the form of liquid coatings which were painted onto the membrane stage elements. All other membrane materials were commercially supplied in sheet form at varying thicknesses. The ratio parameter, R, may therefore only be used as a reference indicator of the effectivenss of the various membrane materials in restricting radon emanation flows. On this basis alone, the results shown in Table 2 indicate that the sulphide copolymer and aluminized mylar membranes offer the greatest restriction potential. The barrier effectiveness against radon flow is, however, directly proportional to the permeability constant values which have been derived; the same approximate order of effect between the two membrane materials is exhibited by the derived permeability constant values.

Of the six membrane materials tested under laboratory conditions, only two are capable of maintaining radon concentrations within initially radon-free environments at levels less than 5% of the source concentration levels. For the polysulphide copolymer, the equilibrium diffusion concentration ratio, R, approximated 4.7%; the aluminized mylar membrane effected substantially better performance, approximating a ratio value of 0.16%. The remaining material suppression ratios varied between 30.0 and 88.6%, approximately, and would not be deemed to be suitable for use as radon barrier materials.

On the basis of such limited laboratory investigations, the application of several membrane coatings has been shown effective in preventing radon gas migration into designated environments under ideal conditions.

A complementary, and also limited, series of in-situ tests was conducted in an underground mining environment to verify the effectiveness of placed membrane materials under dynamic working conditions. Due to time limitations at the mine site, and as per the specific mandate of the host mining company, tests were conducted upon bulkhead surfaces where differential radon concentrations were measured to exist between the bulkhead sides. Limitation of field study intervals precluded continuous monitoring capability. Similarly, the lower limit of scintilla-

tion cell accuracy for radon concentration measurements, under field conditions, required that radon concentrations in excess of 0.3 pCi/L be present. For this reason, concentration data could not be accurately determined during initial emanation chamber sampling tests which were initiated at a time interval approximately 11720 minutes after preliminary airway concentration measurements were begun.

The two most effective barrier materials, as evidenced by laboratory tests, were installed upon the low concentration side of the bulkhead and were henceforth instrumented. The results, listed in Table 3 indicated that equilibrium radon concentrations resulting from emanation flows, approximating 17.4 and 2.6%, respectively, of initially present levels were achieved through use of bulkheads coated by the polysulphide copolymer and aluminized mylar barrier materials. The untreated plywood surface of the bulkhead evidenced a reduction in concentration of approximately 23.5% compared to the source radon concentration level. The plywood, comprising a mixed cellulose fiber, restricted approximately 76.5% of the radon source concentration which was available to emanate through the bulkhead from the sealed stope volume.

Measured emanation rate parameters were similarly listed in the data of Table 3. The flux rate trend indicates that a rapid initial diffusion flow of radon occurs through the untreated and the polysulphide copolymer treated plywood surfaces.

Significantly lower emanation rate behaviour at levels between 4 to 7 percent of the measured levels for the untreated and polysulphide coated barriers, respectively, was monitored for the aluminized mylar barrier.

Variation in airstream radon concentration values versus time, as evidenced in the curves of Figure 4, would indicate either that non-uniform airflow conditions existed or that production activity in the vicinity of the test site existed to alter steady state concentration conditions. Generally uniform source levels in the sealed stope, averaging 100.7 pCi/L, were shown to exist only during the latter half of the emanation chamber test cycle. It is therefore apparent that, should future in-situ membrane trials be conducted, one or more of the following actions would be required:

1) that permanently sealed bulkhead sites be selected, where very high strength source concentrations of radon gas are known to exist in the sealed volume side, or
2) that emanation chamber equipment be installed directly upon emanating rock surfaces.

In both suggested cases higher source concentrations of radon, than presently observed, should be monitored, and all test sites should be shielded from access by underground personnel to preclude fluctuations in ambient concentration conditions.

## 5.0 CONCLUSIONS

The use of wall sealant materials has been demonstrated to be effective in restricting the emanation of radon gas into initially radon-free environments and into simulated radon-free mine environments.

Such application would be suitable for particular environments notably in uranium mining districts where residential and industrial exposure requires that radon contamination be minimized.

Prior to the establishment of the laboratory and in-situ phases of this research project, no minimum criteria for suitability of membrane coatings had been established. It was stated, however, that optimum utilization would be gained where a particular membrane barrier material would yield maximum resistance to diffusion flow of radon. On the basis of test results two membrane materials have been demonstrated to effectively restrict emanation of radon into radon free environments and to thereby satisfy this constraint. The substances, notably aluminized mylar (PT), in sheet form, and a polysulphide copolymer compound (PC), in liquid form, offer promise for radon control applications. Each is capable of reducing radon emission concentratons by better than 95%; the aluminized mylar, in particular, is capable of reducing atmospher concentratons by more than 99.8%.

At this time, sufficient work has not been accomplished to satisfy all problems which may be inherent to residential or industrial application of the optimum barrier membrane materials. Product specification data, either appended to this report or available in reference literature, can be used to partially address suitability criteria for use, which must satisfy some of the following constraints:

a) will the substance(s) reduce radon emission rates effectively?

b) is the membrane material easy to apply in working environments; for underground application, can it be spray painted onto walls?

c) will the membrane material(s) adhere to dry, dusty, wet, porous, and the like, rock or concrete surfaces?

d) will the material cure, if sprayed in liquid form, under harsh environmental conditions of high humidity, temperature etc?

e) will the substance emit toxic or noxious fumes upon and after installation?

f) what will be the cost effectiveness of applying individual membrane substances?

Few such considerations have been addressed to date under the present mandate of this research project. The majority of tests performed have been of the static (sealed chamber) type in carefully regulated environments. Long term, dynamic tests should therefore be considered for future study work to determine the effectiveness of in-situ industrial applications. In this manner, cost effectiveness, health safety and installation guidelines for use of promising barrier materials may be comprehensively assessed.

## ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Atomic Energy Control Board for financial assistance and its willingness to permit this research investigation to be performed.

Special acknowledgement is made, also, to associated mining companies for permission to conduct in-situ experimental studies.

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# APPENDIX

## MATERIAL SAFETY DATA SHEETS

Halltech Inc.

# MATERIAL SAFETY DATA SHEET

## SECTION I

| MANUFACTURER'S NAME | EMERGENCY PHONE NO. |
|---|---|
| HALLTECH INC. | (416) 284-6111 |

ADDRESS (No., St., City and Postal Code)
465 CORONATION DRIVE, WEST HILL, ONTARIO M1E 2K2

| CHEMICAL NAME AND SYNONYMS | TRADE NAME AND SYNONYMS |
|---|---|
| | ROCK COAT 82-3 (ES 76-315-2) |
| CHEMICAL FAMILY: P.V.C. COPOLYMER SOLUTION | FORMULA |

## SECTION II — HAZARDOUS INGREDIENTS

| PAINTS, PRESERVATIVES & SOLVENTS | % | TLV (Units) | ALLOYS AND METALLIC COATINGS | % | TLV (Units) |
|---|---|---|---|---|---|
| Pigments | | | Base Metal | | |
| Catalyst | | | Alloys | | |
| Vehicle | | | Metallic Coatings | | |
| Solvents ACETONE | 70 | 750 PPM | Filler Metal Plus Coating or Core Flux | | |
| Additives | | | Others | | |
| Others | | | | | |

| HAZARDOUS MIXTURES OF OTHER SOLVENTS | % | TLV (Units) |
|---|---|---|
| | | |
| | | |
| | | |

## SECTION III — PHYSICAL DATA

| | | | |
|---|---|---|---|
| Boiling Point (°C) APPROX. 56 | | Specific Gravity ($H^2O$ = 1) | 0.900 |
| Vapor Pressure (mm Hg) APPROX 230 @ 25°C | | Percent Volatile by Volume (%) | - |
| Vapor Density (Air = 1) APPROX. 2 | | Evaporation Rate ( nBA = 1) | 6.0 |
| Solubility in Water SOLUTE PRECIPITATES | | | |
| Appearance and Odour THIN YELLOW LIQUID, | CHARACTERISTIC MINT-LIKE ODOUR | | |

## SECTION IV — FIRE AND EXPLOSION HAZARD DATA

| Flash Point (Method used) | Flammable Limits % BY VOLUME FOR ACETONE | LEL | UEL |
|---|---|---|---|
| 0° F (-18°C) CLOSED CUP FOR ACETONE | | 2.1 | 12.8 |

Extinguishing Media $CO_2$, DRY CHEMICAL, WATER FOG

Special Fire Fighting Procedures FIRE FIGHTERS SHOULD USE SELF-CONTAINED BREATHING APPARATUS. ACETONE FIRES ARE CLASS B; USE BLANKETING EFFECT TO SMOTHER FLAME.

Unusual Fire and Explosion Hazards ACETONE PRESENTS A DANGEROUS FIRE HAZARD AND MODERATE EXPLOSION HAZARD

## SECTION V — HEALTH HAZARD DATA

**Threshold Limit Value** 8 HR TWA 750 PPM

**Effects of Overexposure** ACETONE IS A LOW TOXICITY SOLVENT. IRRITATION OF MUCOUS MEMBRANES, HEADACHE, NAUSEA AND NARCOSIS CAN RESULT FROM EXPOSURE TO VAPOURS. PROLONGED CONTACT WITH SKIN CAN HAVE A DEFATTING ACTION AND MAY RESULT IN DERMATITIS. EYE CONTACT IRRITATING, MAY BE DAMAGING

**Emergency and First Aid Procedures** EYE CONTACT: FLUSH WITH PLENTY OF WATER FOR 15 MIN. SEEK MEDICAL ATTENTION. SKIN CONTACT: WASH WITH WATER. INHALATION: REMOVE VICTIM TO FRESH AIR. IF EFFECTS MORE SEVERE THAN HEADACHE SEEK MEDICAL ATTENTION. RESTORE OR SUPPORT BREATHING IF REQUIRED.

## SECTION VI — REACTIVITY DATA

| | | |
|---|---|---|
| **STABILITY** | Unstable | **Conditions to Avoid** |
| | Stable X | |

**Incompatibility (Materials to avoid)** STRONG OXIDIZING AGENTS SUCH AS NITRATES AND PERCHLORATES, OR CONCENTRATED SULFURIC ACID.

**Hazardous Decomposition Products** CARBON MONOXIDE ON INCOMPLETE COMBUSTION.

| | | |
|---|---|---|
| **Hazardous Polymerization** | May Occur | **Conditions to Avoid** |
| | Will Not Occur X | |

## SECTION VII — SPILL OR LEAK PROCEDURES

**Steps to be Taken in Case Material is Released or Spilled** VENTILATE AREA. GUARD AGAINST FIRE. CLEAN UP SPILL WITH RAGS AND/OR OTHER INERT MATERIAL. FLUSH AREA WITH WATER.

**Waste Disposal Method** CHECK WITH MUNICIPALITY INVOLVED.

## SECTION VIII — SPECIAL PROTECTION INFORMATION

**Respiratory Protection (Specify type)** NOT NORMALLY REQUIRED IF VENTILATION ADEQUATE.

| | | |
|---|---|---|
| **Ventilation** | Local Exhaust YES - TO KEEP VAPOUR CONC. BELOW | **Special** |
| | Mechanical (General) 750 PPM | **Other** |

**Protective Gloves** IMPERVIOUS TYPE **Eye Protection** SAFETY GOGGLES

**Other Protective Equipment**

## SECTION IX — SPECIAL PRECAUTIONS

**Precautions to be Taken in Handling and Storing** STORE IN TIGHTLY CLOSED CONTAINERS IN COOL, WELL-VENTILATED PLACE.

**Other Precautions** ELECTRICALLY INTERCONNECT AND GROUND CONTAINERS FOR ALL TRANSFERS TO AVOID STATIC SPARKS. NO SMOKING IN STORAGE OR USE AREAS.

Form Approved
OMB No. 44-R1387

6/6/78

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

# MATERIAL SAFETY DATA SHEET

Required under USDL Safety and Health Regulations for Ship Repairing, Shipbuilding, and Shipbreaking (29 CFR 1915, 1916, 1917)

## SECTION I

| | |
|---|---|
| MANUFACTURER'S NAME<br>THIOKOL CORPORATION, CHEMICAL DIVISION | EMERGENCY TELEPHONE NO.<br>THIOKOL (609) 396-4001<br>CHEMTREC (800) 424-9300 |
| ADDRESS (Number, Street, City, State, and ZIP Code)<br>P. O. Box 8296, 930 Lower Ferry Rd., Trenton, NJ 08650 | |
| CHEMICAL NAME AND SYNONYMS<br>*Polysulfide rubber latex dispersion* | TRADE NAME AND SYNONYMS<br>*WD-6, WD-6HS, Polysulfide Water Dispersion* |
| CHEMICAL FAMILY<br>*Alkyl polysulfide polymer* | FORMULA<br>*Proprietary* |

## SECTION II - HAZARDOUS INGREDIENTS

| PAINTS, PRESERVATIVES, & SOLVENTS | % | TLV (Units) | ALLOYS AND METALLIC COATINGS | % | TLV (Units) |
|---|---|---|---|---|---|
| PIGMENTS | | | BASE METAL | | |
| CATALYST | | | ALLOYS | | |
| VEHICLE | | | METALLIC COATINGS | | |
| SOLVENTS *water in WD-6*<br>*water in WD-6HS* | 50<br>~25 | | FILLER METAL PLUS COATING OR CORE FLUX | | |
| ADDITIVES | | | OTHERS | | |
| OTHERS | | | | | |

| HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES | % | TLV (Units) |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

## SECTION III - PHYSICAL DATA

| | | | |
|---|---|---|---|
| BOILING POINT (°F.) | *212°F* | SPECIFIC GRAVITY ($H_2O$=1) | |
| VAPOR PRESSURE (mm Hg.) *room temp.* | *20* | PERCENT, VOLATILE BY VOLUME (%) | *25-50%* |
| VAPOR DENSITY (AIR=1) | *<1* | EVAPORATION RATE (*water* =1) | *1* |
| SOLUBILITY IN WATER | *not soluble but dispersible* | | |
| APPEARANCE AND ODOR | *beige-colored, pasty solid wet cake or slurry with disagreeable odor* | | |

## SECTION IV - FIRE AND EXPLOSION HAZARD DATA

| | | | |
|---|---|---|---|
| FLASH POINT (Method used)<br>*N.A. (not applicable)* | FLAMMABLE LIMITS | Lel | Uel |
| EXTINGUISHING MEDIA<br>*Water, carbon dioxide, foam, dry powder* | | | |
| SPECIAL FIRE FIGHTING PROCEDURES<br>*Firefighters should wear self-contained full-face air masks.* | | | |
| UNUSUAL FIRE AND EXPLOSION HAZARDS<br>*Choking fumes emitted from burning material.* | | | |



(Continued on reverse side)

## SECTION V - HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE
10 mg/m³ suggested (as nuisance aerosol)

EFFECTS OF OVEREXPOSURE
Minimally irritating to eye. If WD-6 dries on skin, difficult to remove except by peeling off.

EMERGENCY AND FIRST AID PROCEDURES
If EYE contact occurs, flush immediately with copious amounts of water. If SKIN contact occurs, flush with water. If INHALED, remove to fresh air.

## SECTION VI - REACTIVITY DATA

| STABILITY | | | CONDITIONS TO AVOID |
|---|---|---|---|
| | UNSTABLE | X | Avoid temperatures below 32°F. |
| | STABLE | | |

INCOMPATABILITY (Materials to avoid)
Acids, alkalis, strong oxidizing agents.

HAZARDOUS DECOMPOSITION PRODUCTS
$SO_2$, CO, $CO_2$

| HAZARDOUS POLYMERIZATION | | | CONDITIONS TO AVOID |
|---|---|---|---|
| | MAY OCCUR | | |
| | WILL NOT OCCUR | X | |

## SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Absorb in granular absorbent and sweep up. If spill already dried, scrape up.

WASTE DISPOSAL METHOD
Land burial is preferable. If permitted by state statutes. If incineration is required, high-temperature incineration (with scrubber to remove acid fumes) must be used.

## SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION (Specify type)
For spray application, use dust respirator.

| VENTILATION | | |
|---|---|---|
| | LOCAL EXHAUST: necessary for spray application | SPECIAL |
| | MECHANICAL (General): desirable | OTHER |

| PROTECTIVE GLOVES | EYE PROTECTION |
|---|---|
| recommended; any type suitable | Face shield or monogoggles |

OTHER PROTECTIVE EQUIPMENT Long sleeves suggested; for spray applications, all otherwise exposed body surfaces should be covered up.

## SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING
Keep from freezing. If freezing occurs, irreversible coagulation to a rubbery mass occurs. Water may be added to dilute to a more fluid consistency. Keep container closed to avoid skinning over or drying out.

OTHER PRECAUTIONS
D.O.T. Hazard Classification: Non-hazardous

F.H.S.A. Hazard Classification: Non-hazardous

Thiokol®

LP®
POLYSULFIDE POLYMER TD-569N 5/69

# RADIATION RESISTANCE OF LP® LIQUID POLYSULFIDE POLYMER BASED COMPOUNDS

## INTRODUCTION

Several independent test laboratory studies have been conducted on the radiation resistance of LP® liquid polysulfide based compounds. In one study, an LP liquid polysulfide based compound withstood gamma radiation doses up to $6.6 \times 10^7$ roentgens, for a period of seven days, with little degradation to physical properties. In a second study, specially formulated LP liquid polysulfide based compounds immersed in JP-4 jet fuel withstood as much as $1.7 \times 10^8$ roentgens, with only a small loss in physical properties. Both studies showed that commercially available LP liquid polysulfide polymer base aircraft sealants formulated to meet Federal Specifications MIL-S-7502C and MIL-S-8802C had the best resistance to radiation.

## DISCUSSION OF RADIATION RESISTANCE DATA FROM OTHER REPORTS

One report which contains radiation data is entitled, "Research on Elastomeric and Compliant Materials for Aerospace Sealants", Technical Documentary Report No. ASD-TDR-62-709. In this study, eight different polymer based sealants, which were all proprietary sealants, were evaluated and compared. Of those sealants tested, the LP liquid polysulfide based sealants gave the best resistance to gamma radiation. In testing the LP liquid polysulfide based sealant compounds for radiation resistance, three different curing agents were used. The best radiation and heat resistance results obtained were on those LP polysulfide polymer compounds which used either the chromate* or $MnO_2$ cure as compared to the $PbO_2$ cure. The best results obtained in this study were on an LP liquid polysulfide polymer based compound that withstood gamma radiation doses of $6.4 \times 10^6$ roentgens at temperatures of 190°F for 16 hours. After 100 hours at 250°F, this compound was still serviceable although some degradation was evident.

A second report that contains considerable radiation data on various sealant systems is entitled, "The Effects of Reactor Radiation on Elastomers and Sealants-III", by L. L. Morgan. This is Document No. NARF-60-37T, and is also listed as ASTIA No. 256,689. In this study, a number of proprietary compounds, as well as compounds prepared by Thiokol, were evaluated against a number of combined environments. The maximum gamma dosage which LP liquid polysulfide based sealants withstood, when exposed in air at 90°F, was $1.7 \times 10^8$ roentgens. After this maximum gamma radiation exposure, the samples still exhibited tensile properties of 400 psi and elongation values of 265%.

**U.S. Patent No. 2,787,608 issued 4/2/57 to Products Research Company, Los Angeles, Cal. should be referred to before processing and marketing commercial products based on the chromate cure system.*

Thiokol/ CHEMICAL DIVISION 930 Lower Ferry Road P.O. Box 1296 Trenton, N. J. 08607 (609) 396-4001

® Registered trademark of Thiokol Corporation.

The information in this bulletin is derived from the best available sources and is believed to be accurate. However, no guarantee is expressed or implied regarding the accuracy of these data or the use of this product, nor are any statements in this bulletin intended to infringe on any patent.

In another test, cured tensile specimen samples of several LP liquid polysulfide polymer based sealant compounds were immersed in JP-4 fuel for seven days. Next, the samples received a gamma dose of $1.7 \times 10^8$ roentgens, after which they were left immersed in the JP-4 fuel for thirty more days. After completion of the exposure tests, the samples still exhibited a tensile strength of 350 psi and an elongation of 125%. The LP liquid polysulfide polymer based compounds used in these exposure tests were based on a chromate and $MnO_2$ cure system.

Refer to Table I for typical LP liquid polysulfide polymer based formulations and the physical and heat resistant properties of the cured compounds. Then, refer to Tables II and III for a summary of results on five cure systems and their correlation between radiation and heat resistance. All data in the following Tables was compiled from tests conducted by Convair, a division of General Dynamics, Fort Worth, Texas. Convair conducted all the irradiation studies on the test samples, which were prepared and supplied by Thiokol Chemical Corporation. Among the sealants formulated by Thiokol, it was established that cure systems exhibiting the best heat resistance also exhibited the best radiation resistance. Exposure to higher temperatures during irradiation indicated that heat alone can cause degradation.

## TABLE I

## PHYSICAL PROPERTIES OF COMPOUNDS BASED ON THIOKOL'S LP-32 POLYMER

| Compound (pbw) | A | B | C | D | E |
|---|---|---|---|---|---|
| LP-32 Polymer | 100 | 100 | 100 | 100 | 100 |
| Titanox RA-50 | – | 50 | – | – | – |
| EH-330 | – | – | 1.2 | – | – |
| 25% Maleic Anhydride in Cyclohexanone | – | – | 2 | – | – |
| Durez 10694 | 5 | – | – | 5 | – |
| SRF #3 | 30 | – | – | 40 | 30 |
| MgO | – | – | 4 | – | – |
| Sulfur | 0.1 | – | – | 0.1 | – |
| Stearic Acid | 1 | – | – | 1 | – |
| Cumene Hydroperoxide | – | – | 6 | – | – |
| 50% $TeO_2$ in Dibutyl Phthalate | – | 4 | – | – | – |
| 50% $PbO_2$ in TP-680 | 15 | – | – | – | – |
| 43% Ammonium Chromate Solution in $H_2O$ | – | – | – | 15 | – |
| Cabosil M-5 | – | – | 20 | – | – |
| Sodium Stearate | – | 5 | – | – | – |
| $MnO_2$ - "D" Grade | – | – | – | – | 3 |
| **Original Physical Properties** | | | | | |
| Tensile, psi | 390 | 310 | 435 | 800 | 390 |
| 300% Modulus, psi | 240 | 780 | 130 | 610 | 280 |
| Elongation, % | 500 | 530 | 910 | 590 | 435 |
| Hardness, Shore A | 50 | 33 | 46 | 61 | 50 |
| **Physical Properties After One Week at 158°F.** | | | | | |
| Tensile, psi | 550 | 360 | 520 | 910 | 810 |
| 300% Modulus, psi | 300 | 150 | 165 | 610 | 310 |
| Elongation, % | 540 | 630 | 830 | 490 | 700 |
| Hardness, Shore A | 53 | 50 | 48 | 62 | 50 |
| **Physical Properties After One Week at 212°F.** | | | | | |
| Tensile, psi | 710 | 420 | 870 | 950 | 780 |
| 300% Modulus, psi | 380 | 140 | 290 | 680 | 290 |
| Elongation, % | 440 | 750 | 740 | 460 | 710 |
| Hardness, Shore A | 57 | 49 | 57 | 64 | 48 |
| **Physical Properties After One Week at 250°F.** | | | | | |
| Tensile, psi | 540 | 350 | 800 | 710 | 430 |
| 300% Modulus, psi | | 120 | 460 | 510 | 160 |
| Elongation, % | 190 | 850 | 460 | 420 | 750 |
| Hardness, Shore A | 64 | 48 | 58 | 57 | 43 |

## TABLE II

### PHYSICAL PROPERTIES OF EXPERIMENTAL SEALANTS, BASED ON THIOKOL'S LP-32 POLYMER, AFTER IRRADIATION IN AIR AT 90° F.

| Compound | Gamma x $10^7$ | Neutron x$10^{15}$ | Tensile, psi | Elongation, % |
|---|---|---|---|---|
| A | 0 | 0 | 480 | 525 |
| | 1.4 | 1.4 | 460 | 490 |
| | 10.1 | 8 | 300 | 210 |
| | 10.1 | 7 | 250 | 160 |
| B | 0 | 0 | 450 | 700 |
| | 1.5 | 1.3 | 420 | 720 |
| | 10.1 | 8 | 260 | 280 |
| | 10.1 | 7 | 170 | 200 |
| C | 0 | 0 | 820 | 670 |
| | 1.4 | 1.3 | 580 | 560 |
| | 10.1 | 7.1 | 420 | 320 |
| | 10.1 | 7 | 400 | 260 |
| D | 0 | 0 | 1230 | 570 |
| | 2.2 | 1.3 | 1140 | 440 |
| | 10.1 | 7 | 650 | 210 |
| | 10.1 | 7 | 530 | 160 |
| E | 0 | 0 | 570 | 500 |
| | 2.2 | 1.3 | 480 | 450 |
| | 8.4 | 7 | 280 | 250 |
| | 17.4 | 10 | 250 | 210 |

Gamma irradiation in Roentgens, but originally expressed as ergs/gm. (C)
Neutron irradiation in n/cm$^2$ where E>0.33 MEV

## TABLE III

## PHYSICAL PROPERTIES OF EXPERIMENTAL SEALANTS BASED ON THIOKOL'S LP-32 POLYMER, AFTER IRRADIATION AND IMMERSION IN JET FUEL

| Compound | Gamma x $10^7$ | Neutron x$10^{15}$ | Tensile, psi | Elongation, % |
|---|---|---|---|---|
| A | 0 | 0 | 480 | 540 |
| | 2.9 | 1.2 | 290 | 340 |
| | 11.3 | 7 | 60 | 40 |
| B | 0 | 0 | 340 | 670 |
| | 2.9 | 1.2 | 160 | 240 |
| | 13.0 | 6 | 20 | 50 |
| C | 0 | 0 | 740 | 650 |
| | 2.9 | 1.2 | 570 | 620 |
| | 13.0 | 7 | 170 | 110 |
| D | 0 | 0 | 1020 | 530 |
| | 17.2 | 1 | 350 | 120 |
| E | 0 | 0 | 600 | 530 |
| | 11.5 | 8 | 115 | 70 |

Treatment (JP-4 immersion 7 days at 75°F., irradiation during immersion followed by 30 days immersion in JP-4 Fuel at 75°F.).
Gamma irradiation in Roentgens, but originally expressed as ergs/gm. (C)
Neutron irradiation in n/$cm^2$ where E>0.33MEV

## LIST OF BRAND NAME COMPOUNDING INGREDIENTS

| Material Trade Name | Chemical Composition | Manufacturer |
|---|---|---|
| TP®-680 | Polymeric | Thiokol/Chemical Division |
| Cabosil M-5 | Fumed silica | Cabot Corporation |
| Durez 10694 | Phenolic resin | Hooker Chemical Corp. |
| EH-330 | Catalyst, tertiary amine | Thiokol Chem. Corp. |
| $MnO_2$ - "D" grade | Manganese dioxide, special grade $MnO_2$ | Manganese Chemical Corporation |
| Titanox RA-50 | Titanium dioxide | Titanium Pigments Corporation |